https://erjm.journals.ekb.eg
ISSN: 2203-1155 (R1)

DOI: ---------

ERJ
Engineering Research Journal
Faculty of Engineering
Menoufia University

Hybrid Photovoltaic-Thermal Solar Systems for Combined Heating, Desiccant Cooling and Power Generation for a Residential Building

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ABSTRACT
The concept of net zero energy buildings has recently taken a great attention in future building. Energy conservation and efficiency techniques must be completely utilized in order to attain a zero energy balance on an annual basis. However, in most building and under most climatic situations, there will be a necessity for active heating and/or cooling as well as the electricity demand. Solar energy is the most common renewable energy source, and it may be used to fulfill a large portion of the energy demand in buildings. Heating and/or cooling are the primary energy demands in buildings, depending on local climatic conditions and building form. In this paper, we look at some of the most effective strategies to meet a portion of the demand for heating, cooling, power generation for residential building. This study presents three possible alternative technologies for supplying the needed cooling and heating loads of 27.26 kW and 9 kW, respectively. This parametric study will result in energy savings of more than 80% for cooling and heating systems. It is found that the payback period for solar electricity system by PV is around 7.5 years.

Keywords: *Desiccant, cooling, solar heating, electricity generation, energy saving, cost saving.*

1. Introduction

Energy generation, which is critical in today's world, is a top priority for all countries and governments. However, because the majority of energy sources are non-renewable, they can't be supplied quickly. Since the 1990s, energy specialists have been focused on solar energy as a renewable source of energy [1, 2]. Furthermore, cooling, heating, and electricity generation reflect a residential building's entire power requirement in Lebanon and around the world, where cooling and heating systems consume between 55 and 70 percent of the total electrical power required. Lighting, household appliance usage, dehumidifying, ventilation, and domestic water heating account for the remaining consumption [3].

Furthermore, the energy sector accounted for 87 percent of greenhouse gas emissions in Lebanon in 2012 [4]. The major goal of this parametric analysis is to ensure comfort conditions in summer with 24°C and 50% relative humidity and decrease power usage in winter with 22°C and 30% relative humidity [5]. Due to the use of compressors and condensers, traditional systems employ harmful substances and consume a lot of power in mechanical compressor. This study also aims to investigate new proposed systems such as solar desiccant cooling, solar heating, and photovoltaic systems, all of which attempt to reduce the amount of energy required for cooling demand by reducing moisture content. The number of components, size, and performance of each system will be evaluated. Furthermore, the energy and cost savings will be calculated.

Clean energy system is the main goal that energy and environment experts are looking for. Ramos et al. [6] studied a photovoltaic-thermal system (PV/T) that takes the lead on the renewable energy systems. The analysis is divided into three main topics: Cooling, Heating, and Electricity Generation. The study focused on two types of cooling and heating systems: Passive and Applied Systems. The solar-powered systems depicted in Figure 1 can be used in residential buildings. PV-T systems are being considered, which are combined with a small-scale thermally driven solar-cooling system (absorption refrigerator or heat pump) and thermal energy storage technology to increase system autonomy [6].

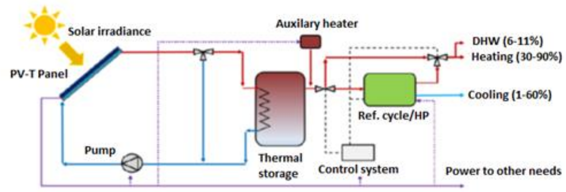


Figure 1- Schematic diagram for solar cooling and heating system [6]

2. Aim and Research Significance

The present work aims to investigate some of the most effective strategies to meet a portion of the demand for heating, cooling, power generation for residential building. The originality of the work resides in the following points

➢ Description of operation principles of hybrid solar desiccant cooling, heating, and PV power generation systems.

➢ Parametric analysis and performance evaluation aiming to select and optimize the suitable target units.

➢ Evaluate the energy and cost saving by comparing the recent proposed system relative to the traditional units.

3. System Description

I. Cooling Systems

The use of particular structures that reduce heating and cooling loads, such as double walls separated by resistive materials like cork, double glass, blinds, and shade, are examples of passive cooling systems [7]. Cooling is the removal of heat energy from a conditioned space or from supplied air to compensate for the energy gained by the surrounding space. The vapor compression refrigeration cycle, absorption refrigeration cycle, and adsorption refrigeration cycle are the three most common air conditioning systems. Condenser, evaporator, compressor, expansion valves, and suction and discharge pipes comprise the vapor compression refrigeration cycle. This cycle is dependent on a refrigerant that circulates within the system, and the refrigerants that are commonly used or promoted for use are R-134a, R-410a, and R-407c, as R-22 and R-123 will be phased out of air conditioning systems by 2030 for environmental, safety, and cost reasons [8]. Absorption systems are similar to vapor compression refrigeration systems, but the difference is only in the pressurization stage or compression process. The compressor in the VCRC is substituted by an absorber, heat exchanger, and generator. In this system, there exists an absorber that is found in the low pressure side where there is an absorbent that absorbs a refrigerant after it flows from the evaporator. In the absorber, the mostly used fluids are the lithium bromide–water (liBr-H_2O) or calcium chloride-water (CaCl-H_2O); its usage is limited due to crystallization that occurs in the pipes and lead to malfunctioning of the system [9]. Adsorption refrigeration cycle which is also called solid sorption refrigeration cycle uses solid sorption material such as Silica gel and Zeolite to produce cooling effect. Adsorption is a process where a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent) forming a molecular or atomic film (absorbate), while desorption is the opposite of it.

The proposed cooling system is the Desiccant Cooling Cycle (DCC). It is a direct conditioning of the air. This system is based on chemical material called desiccant, and the desiccants commonly used are silica gel or zeolite for their high adsorption capacity. Figure 2 illustrates the complete cycle of the desiccant cooling system. It consists of two Cycles: Supply Cycle and Return Cycle [10].

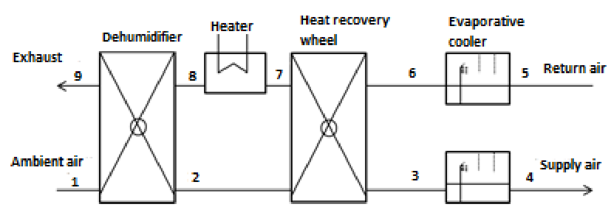


Figure 2- Desiccant cooling system [10]

The main components of desiccant cooling system consist of:

- ***Desiccant wheel***

Figure 3 indicates a desiccant wheel that rotates very slowly as the inlet air passes through it. The particles of the desiccant absorb the latent load from the air, lowering its humidity. The high temperature return air, on the other hand, passes through the wheel in the return cycle to regenerate the desiccant and return it to its initial state in order to re-dehumidify the air in the next supply cycle.

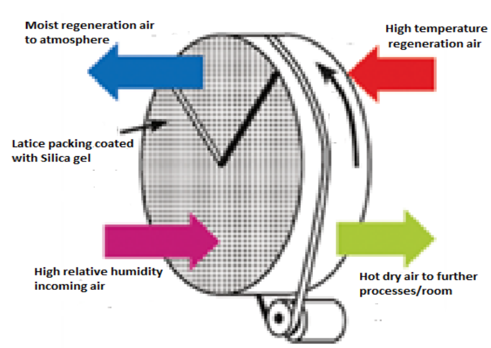


Figure 3- Desiccant wheel function [11]

- ***Thermal Wheel***

Figure 4 shows a thermal wheel that has a dual function: in the summer, it absorbs heat from the input air, and in the winter, it adds heat to the same stream. In the summer, heat transfer occurs between the conditioned zone's low-temperature, high-humidity return air and the desiccant wheel's high-temperature, low-humidity supply air. Effective heat transfer occurs between the high and low latent load air combinations in the thermal wheel.

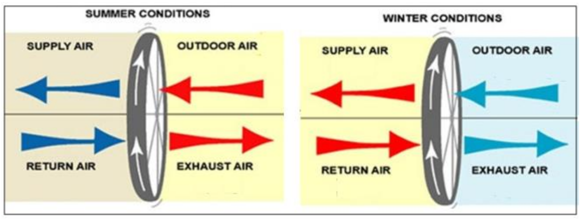
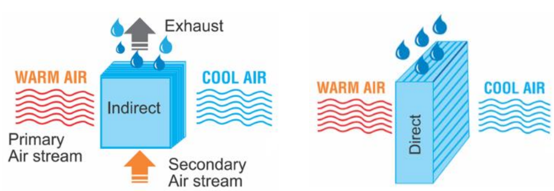


Figure 4- Thermal wheel used in desiccant system

- ***Direct and Indirect Evaporative Coolers***

Figure 5 shows the difference between them. In the indirect evaporative cooling, the primary air is cooled sensibly with a heat exchanger, while the secondary air carries away the heat energy from the primary air as generated vapor. On the other hand, through the direct type; water evaporates directly into the air stream, thus reducing the air temperature while humidifying the air.



Indirect Evaporative Cooling *Direct Evaporative Cooling*

Figure 5- Direct and Indirect Evaporative Cooling

- ***Air-Water Heat Exchangers***

Heat can be transferred from air to water or vice versa using air-water heat exchangers, depending on the system's requirements.

II. Heating Systems

Heating is used to either raise the temperature of a low-temperature room or to compensate for energy lost to the surroundings. Direct radiations and free convection into the room, as well as the transfer of electricity or heated water to devices in the room, can cause heating. Common heating systems that rely primarily on nonrenewable energy sources such as fossil fuel or gas include furnaces, boilers, heat pumps, and electric heating [12]. Solar heating systems, which are widely used in developed countries, are the best option for avoiding reliance on nonrenewable energies [13]. This system consists of an air-liquid heat exchanger, a storage tank, solar collectors, and other components.

III. Electricity Generation

Electricity demand rises as a result of the technological revolution and the wide range of electrical equipment available. Chapin D. et al. [14] published the first Photovoltaic technology in the United States in 1954 to increase the sources of electricity by a new source, which is solar energy, with three different criteria such as grid intertied, grid intertied with battery backup, and off-grid [15]. Grid interconnected with battery backup ensures electricity supply without cut off in low irradiance intensity periods and is profitable in high irradiance periods in which UNDP CEDRO project phase 4 with cooperation with EDL (Electricite du Liban) and LCEC (Lebanese Center for Energy Conservation) assures and supports the Net-Metering policy. The 'Net Metering' concept is based on the flow of current in both directions, from customer's solar energy grid to the utility grid and vice versa using a bi-directional meter knowing that EDL offers free installation of the net-metering [16]. The photovoltaic system consists of PV panels, batteries, inverter, charge controller, net metering and other auxiliaries.
The rising demand for electricity in residential buildings for cooling, heating, lighting, and other devices that require electricity, as well as the problems caused by non-renewable energy sources, are compelling reasons to replace the old system with renewable solar energy systems, whether for cooling and heating or for electricity generation. A parametric investigation will be conducted in the proposed system for the cooling, heating, and electric power systems that were discussed for the residential building, taking into account the main goals of comfort, safety, reliability, and cost effectiveness.

4. Methodology

Three main systems are presented which the centralized desiccant cooling system, centralized solar heating system and photovoltaic system. The first step is to calculate the loads of each system and describe the case under consideration. The analysis will include a parametric study of each system, component sizing, performance, and, finally, an energy and economic comparison of the proposed system to commonly used systems. The cooling and heating loads of a middle-class one-story residential building with an area of 227 m^2 in a Lebanese village in Lebanon's Coastal Southern region are estimated to be 27 kW and 9 kW, respectively. The building's structure included a double wall separated by cork, double glazing with a reflective color, asphalt sheathing on the roof, and venetian blinds for the windows.

4.1. *Desiccant Cooling System*

This system is indicated in Figure 6. The first step after estimating the cooling load is to calculate the flow rate required for the conditioned zone using equation 1 as follows:

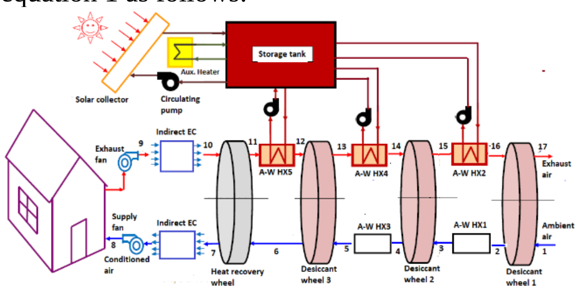


Figure 6- The proposed desiccant cooling system

$$\dot{m}_{air} = \frac{\dot{q}}{(i_{return} - i_{supply})} \quad (1)$$

Because the primary function of a desiccant wheel is dehumidification, it is critical to estimate the rate of moisture removal using equation 2 as follows:

$$\dot{m}_{moisture} = \dot{m}_{air}(w_1 - w_2) \quad (2)$$

Where,

w : is the humidity ratio

The adsorption process in the desiccant wheel is exothermic; therefore, for improved system performance, the heat rejected from this stage is used to heat water for use in the return stream via an air-water heat exchanger located after the desiccant wheel. Because of the high flow rate, as well as design and manufacturing constraints, this system will require more than a single wheel to achieve the desired results. The rotary heat exchanger ensures that heat is transferred between the supply and return streams in a sensible manner. The energy balance in this wheel and the effectiveness can be expressed by:

$$\sum \dot{m}i_{inlet} = \sum \dot{m}i_{exit} \quad (3)$$

$$\varepsilon = \frac{T_{11} - T_{10}}{T_6 - T_{10}} \quad (4)$$

The volumetric flow rate of water is the main parameter to be determined in the direct evaporative cooling system, and it can be estimated using equation 4 as follows:

$$\dot{V}_w = \frac{\dot{q}}{c_w . \rho . \Delta T_w} \quad (5)$$

The main goal of the return stream is to reach the regenerative temperature of the silica gel used in the desiccant wheel, which is 70 degrees Celsius. To improve the effectiveness of the rotary heat exchanger, an indirect evaporative cooling unit should be considered in the return stream. In addition to the proposed air-water heat exchangers between every two wheels, these heat exchangers are supplied by hot water from a solar heating system that includes storage and solar collectors, with the water exiting the supply air-water heat exchangers entering the storage tank, reducing the amount of heat energy required.

Through the solar collector, the energy balance equation can be written as;

$$\dot{m}_w C_w \Delta T_w = A_c \eta_c G \quad (6)$$

Where;

$\dot{m}_w$: is the water mass flow rate through the solar collector

C_w: is the water heat capacity

ΔT_w: is water temperature difference

A_c: is the collector area

η_c: is the collector efficiency

G: is the solar irradiance

4.2. *Solar Heating System*

Figure 7 shows a solar heating system based on an air-water heat exchanger that receives heat from the solar collector and attached storage tank. Fans circulate hot air throughout the space. In order to reduce the consumption of solar energy, a portion of the return air will be extracted and mixed with the supply air. Equation 1 is used to calculate the air mass flow rate and hot water volumetric flow rate of the heating system design. The heating system analysis is divided into two stages: the first is for the start-up process, and the second is for the steady process, which involves mixing a portion of the return air with the inlet ambient air for energy savings purposes. The solar water heating system is being evaluated based on the amount of water required and the weather conditions, which indicate that Lebanon is located in a high irradiance region [17].

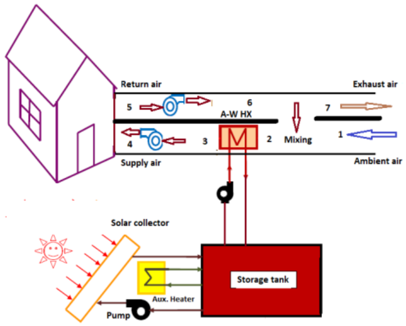


Figure 7- The proposed solar heating system

4.3. *Photovoltaic System*

The first step in analyzing the electricity generation system is to determine the building's electrical demand. Lighting and electronic appliances that are frequently or seasonally used are examples of electrical equipment. Furthermore, the most important components to be powered by this system are the cooling and heating system's equipment, such as the motors that will drive the wheels, the pumps that will circulate the water, fans, and other auxiliaries. PV panels, batteries, a charge controller, an inverter, and other auxiliary components are required for the photovoltaic system shown in figure 8. The required area for PV panels can be estimated based on Table 1.

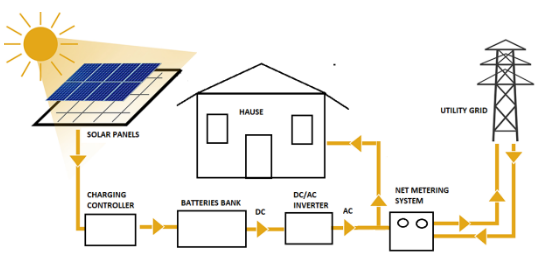


Figure 8- Schematic diagram of the solar electricity generation system's components.

Furthermore, the net metering technique should be considered because EDL (Electricite du Liban) and LCEC (Lebanese Center for Energy Conservation) guarantee and support this policy, which is based on the flow of current in both directions, from the customer's solar energy grid to the utility grid and vice versa, using a bi-directional meter, and EDL offers free net-metering installation [18].

Table 1- Surface area needed for different module types to generate 1 kW under standard test conditions (STC) [19]

Material	Area required for 1 kW
Mono-crystalline silicon	5-7 m^2
Polycrystalline silicon	6-8 m^2
Amorphous silicon	11-17 m^2

4.4. *Economic and Energy Savings*

A commonly used system is being considered for feasibility study and energy comparison between the proposed system and the equivalent system that can supply the same load and operate in a similar period of time for cooling and heating purposes. This equivalent system is expected to be based on a split unit system that is powered by the utility grid and a private sector electricity supplier.
For energy comparison purposes, it is assumed that the proposed systems will be powered by conventional electricity sources such as the utility grid and private generators in order to assess the system's performance. The capital and operating costs of each system will be considered from an economic standpoint. The payback period on the solar electricity generation system with the usual consumption of electricity will be included in the photovoltaic system cost study.

5. Results and Discussion

5.1. *Desiccant Cooling System Analysis*

The air mass flow rate of the cooling system is calculated by multiplying equation 1 by 2.81 kg/s. The desiccant wheel has a thickness of 200 mm, and the maximum moisture absorption in each stage is approximately 10 g_v/kg_a. The proposed system will consist of three stages in order to achieve the desired humidity ratio. The moisture removal rate is calculated to be 0.0945 kg_v/s. The absorption process in the desiccant wheel is exothermic, and the heat produced is used to heat up water for use in the regeneration process via heat exchangers located between each stage. Table 2 shows the characteristics of each point in the proposed cooling system.

Table 2- The characteristics of each point in the desiccant cooling cycle

Points	T_{db} (^oC)	W (g_v/kg_a)	RH (%)	T_{wb} (^oC)	υ_a (m^3/kg)	i (kJ/kg)
1	40	43.65	90	37.3	0.95	152.6
2	68.7	33.5	17.5	39.1	1	157.6
3	40	33.5	70.1	33.8	0.94	126.4
4	68.7	23.4	12.5	5	1	130.5
5	40	23.4	50	29.5	0.94	100.5
6	68.7	10	6	4	0.98	95.4
7	31.3	10	35	20	0.88	57.1
8	16	10	77	13.3	0.83	38.7
9	24	9.3	50	16.8	0.85	47.8
10	18	9.3	72.3	14.6	0.84	41.7
11	55.4	9.3	9.2	26.1	0.94	80
12	70	9.3	5	29.4	0.99	95
13	41.5	19.24	38	28.4	0.92	91.4
14	70	19.2	9.7	5	0.99	120.9
15	41.5	29.14	56.7	32.3	0.93	116.8
16	70	29.14	14.5	36.8	1	147
17	41.5	39.34	75.4	36.1	0.95	143.1

The cooling process in the supply stream is represented on the psychometric chart as sown in Figure 9 from point 1 to point 8.The multi-stage dehumidification process is superior in terms of design, noise, installation, and maintenance. The dehumidification process has been carried out through three desiccant wheels as shown in Figure 6 from point 1 to 2, from 3 to 4, and finally from 5 to 6. In these processes, the humidity ratio decreases while the temperature increases due to the adsorption released heat. From point 6 to 7, the air is sensibly cooled in the rotary wheel, and from point 7 to 8, the indirect evaporative cooling system is responsible for temperature reduction without affecting the humidity ratio.

As shown in Table 3, dehumidification and heating occur within the desiccant wheel at each stage.

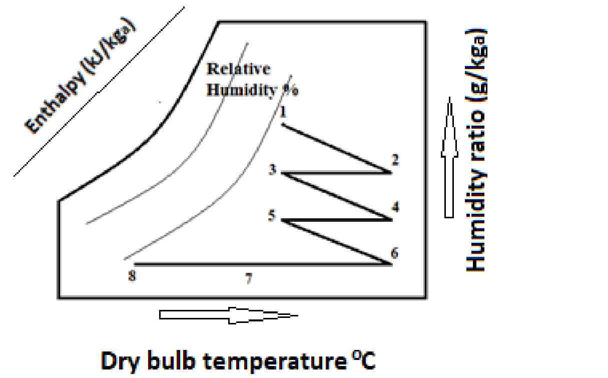


Figure 9- Dehumidification and cooling from point 1 to point 8 on psychometric chart.

Table 3- Dehumidification process in each stage

Heat\Process	Sensible (kW)	Latent (kW)
1 to 2	87.39	73.34
3 to 4	87.67	76.15
5 to 6	84.3	98.6

The variation of the input parameters on this system is being studied in order to detect the system's behavior. Figure 10 depicts the variation in humidity ratio and dry bulb temperature during the hot months in Lebanon's coastal area. The maximum humidity ratio and dry bulb temperature are obtained during July. The air volume flow rate $\dot{Q}_a$ is estimated to be 2.303 m^3/s. The processing velocity is assumed to be 2.71 m/s; based on this information, the diameter of the desiccant wheel should be approximately 1.5 m.

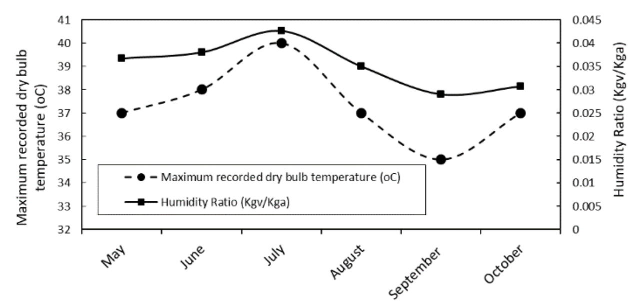


Figure 10- The humidity ratio and dry bulb temperatures in the hot months in coastal south region in Lebanon

The speeds of desiccant wheels with relevant driving motors are listed in Table 4 [20].

The indirect evaporation cooling system is in charge of ensuring that there is enough water to reach the desired temperature.

Table 4- Desiccant wheels speed with relevant driving motors [20]

Desiccant Wheel (D.W)	Speed of Rotation in rph	Speed of driving motor in rph	Drive Motor Power in Watt
D.W 1	45	90	180
D.W 2	42	84	168
D.W 3	50	100	200

Using equation 5, the volumetric flow rate of water in the supply and return streams of indirect evaporative coolers is estimated to be 1.156 L/s and 0.615 L/s, respectively. The effectiveness of the rotary wheel is set to 73 percent, and the characteristics of point 11 are calculated using equation 4. Based on the literature review, the regeneration temperature of the silica gel used in the desiccant wheel is assumed to be 70 degrees Celsius. The air enters the heat exchangers in the return stream at point 11 with a temperature of 55.4 °C and exits at point 12 with a temperature of 70 °C. Assume the inlet water temperature to the heat exchanger is 50°C, and the outlet temperature is 44°C. In Lebanon, typical solar irradiance in a sunny climate is approximately 6 kWh/m^2.day, while in a cloudy climate it is approximately 3 kWh/m^2.day. For a 300 L tank, multiply 300 L by 56 to get a 5.35 m^2 solar array size. A common array size of 1.2 x 2.4 (2.88 m^2) and 1.2 x 2.1 (2.88 m^2) (2.5 m^2). The array consists of two parallel-connected panels. Two components will control the system: the indirect evaporative cooling system and the air-liquid heat exchanger. To control the flow rate of the water, a thermostat will be installed in the upstream line of these components.

Figure 11 illustrates the required water flow rate at various months, as these values vary due to changes in weather conditions and requirements. The minimum flow rate is found in July because the temperature is on its peak value in this month, requiring less hot water.

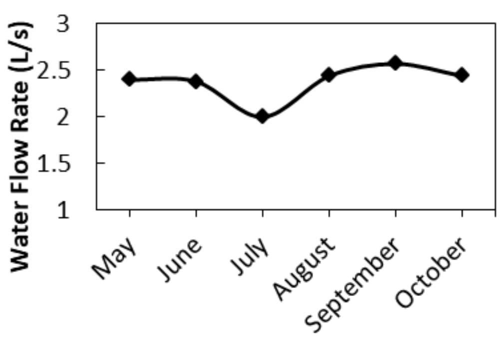


Figure 11- Water flow rate to be supplied to air-liquid heat exchanger.

5.2. *Solar Heating System*

By using equation 1, the air mass flow rate for the heating system is estimated to be 1.451 kg/s. The water entering the heat exchanger has a temperature of 50°C. Assume a temperature efficiency of 80%. The outlet water temperature will then be 38°C. The required exit air temperature is 28.2 °C, with a minimum inlet air temperature of 10°C. Table 5 lists the characteristics of each of the points labeled in Figure 7.

Table 5- The characteristics of each point in the solar heating system

Points	**1**	**2**	**3**	**4**	**5**	**6**	**7**
T_{db} (^oC)	10	10	28.2	28	22	22	22
W (g_v/kg_a)	5.32	5.32	5	4.9	4.9	4.9	4.9
RH (%)	70	70	21	21	30	30	30
υ_a (m^3/kg)	0.81	0.81	0.86	0.86	0.84	0.84	0.84
i (kJ/kg)	23.5	23.5	41.1	40.7	34.6	34.6	34.6

Figure 12 shows the variation of temperature and enthalpy in the cold months in coastal region in Lebanon. The obtained results show that the minimum temperature is about 10 ^oC during January.

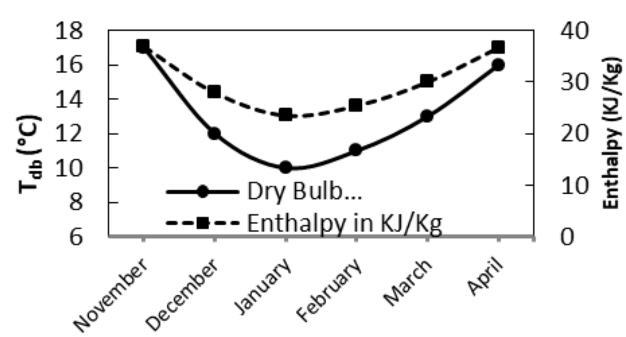


Figure 12- Dry bulb temperature and enthalpy of the six cold months in coastal region in Lebanon

The study of the heating system includes two stages, the first step is the start-up stage and the performance of the system is represented in Figure 13 as the hot water flow rate entering the heat exchanger. This figure indicates also the variation in the hot water flow rate in the steady state that occurs after mixing between the return air and the ambient air.

During the winter months, clouds may trap the sun's rays, resulting in a solar irradiation of 3 kWh/m^2.day. 300 liters divided by 28 equals 10.71 m^2. Then four 1.2x2.4 solar panels are required to supply the required energy. Because of the low clearness index and low temperatures in the winter, the number of solar collectors required for a heating system is large. In addition to the extra panels required to meet the required demand, the solar collectors used in the cooling system will be used in the heating system.

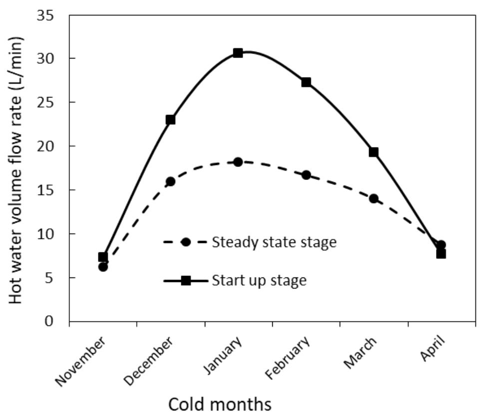


Figure 13- Hot water flow rate entering the air-liquid heat exchanger

5.3. *Electricity Generation System*

Summer and winter electrical loads are estimated to be 158.4 kWh/day and 158.7 kWh/day, respectively. Assume a 30% energy loss in the system, and the total watt-hour/day that the panels should provide is 206.3 kWh/day. Lebanon has approximately 300 sunny days per year, with more than 8- 9 hours of daily sunshine [21]. The daily wattage that the panels should provide is then 25.789 kW. According to table 1, the total area required to achieve the target power is 180.5 m^2 of mono-crystalline plates.

5.4. *Energy and Economic Savings*

A commonly used system is being considered for feasibility studies and energy comparisons between the proposed system and an equivalent system capable of supplying the same load and operating for a comparable period of time for cooling and heating purposes. This equivalent system is expected to be based on a split-unit system powered by the utility grid and a private sector electricity supplier. As shown in Figure 14, a solar-powered system can contribute to an energy reduction of more than 80% for cooling and heating systems, reducing the reliance on non-renewable energy. This reduction may be attributed to the absence of compressive, evaporative, and condensing components.

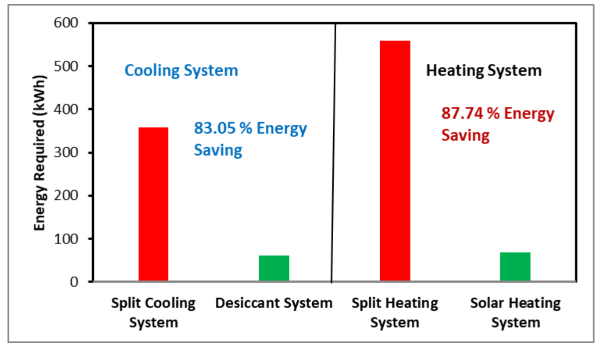


Figure 14- Energy Savings between the proposed system split system for cooling and heating.

Figure 15 shows a comparison of commonly used split units and a desiccant cooling system, which saves approximately 16,000$ in operating costs. Although the capital cost is somewhat high, the operating savings can have a significant impact on the viability of renewable energy systems.

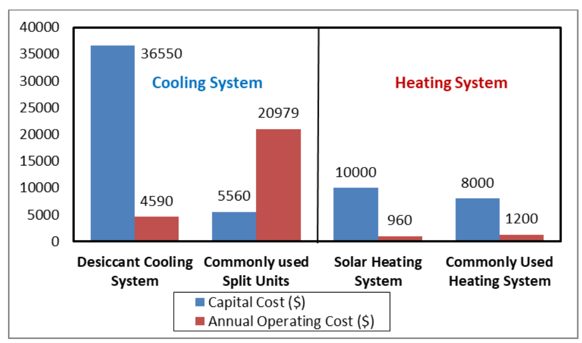


Figure15- Comparative cost analysis between the standard and the proposed systems

A photovoltaic system with a capacity of 30 Amperes is considered for comparison purposes because it is sufficient for the studied residential building. Furthermore, as illustrated in Figure 16, the capital cost of the PV system can be repaid in 7.5 years, and excess power production can be reverted to the utility electric service on paid costs, allowing indirect income to be considered. Based on Table 1, 30 Amperes system necessitates approximately 42 panels of mono-crystalline plates.

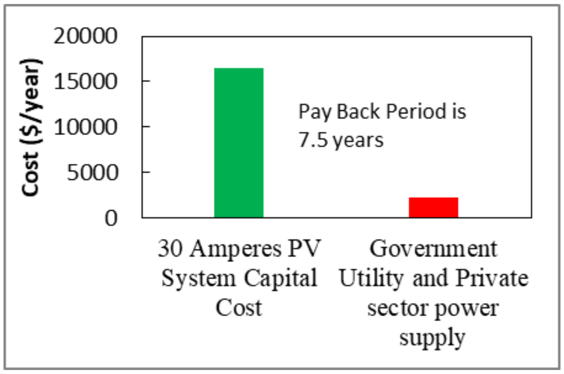


Figure 16- Photovoltaic cost analysis as compared to electricity consumption from government grid and private sector.

6. Conclusion

The parametric analysis of the proposed solar cooling/heating and power generation systems that supply the required demand is detailed in this paper. This system has been evaluated for a 227 m^2 residential building with cooling and heating loads of 27 kW and 9 kW, respectively. It has been discovered that this system requires three desiccant wheels to reduce relative humidity by 40%. Furthermore, the space heating system is comprised of one air water heat exchanger that produces an average of 12 LPM of hot water. This study concluded that the energy savings are approximately 80% when compared to traditional equivalent techniques. It is discovered that 42 m^2 PV mono-crystalline panels are required for 30 Amperes of electrical demand. From an economic standpoint, this system is viable, with a payback period of 7.5 years for the photovoltaic system. The analysis of the systems may differ from one region to the next depending on the weather and location.

These systems are a promising alternative energy solution that ensures the required demand while avoiding the use of chemical substances that are harmful to the environment while consuming less power. Because of the scarcity of power sources and the pollution caused by the use of non-renewable substances, green energy systems are the most influential systems today.

Nomenclature:

A	Solar collector area
A-W HX	Air water heat exchanger
DHW	Domestic hot water
DW	Desiccant wheel
db	Dry bulb
EC	Evaporative cooler
HP	Heat pump
i	Enthalpy
$\dot{m}$	Mass flow rate
PV	Photovoltaic
PV-T	Photovoltaic-thermal
$\dot{q}$	Cooling load
RH	Relative humidity
T	Temperature
t	Time
$\dot{V}$	volume flow rate
υ_a	Air specific volume
ω	Humidity ratio
wb	Wet bulb

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